Effects from the Catastrophic Rupture of a Coal Fly Ash Settling Pond in Kingston, TN

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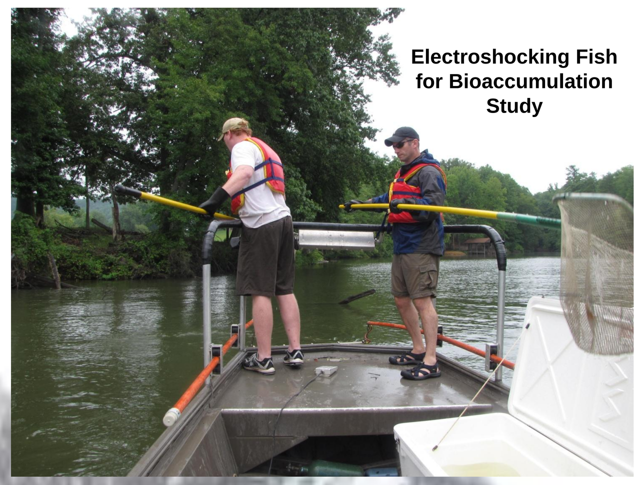
A channel catfish collected from ERM 2.2 weighed 439 grams and contained 34 grams of ash in the gut & intestines (=7.7% of the body weight).



Abstract

At 1am on December 22nd, 2008 the sixty-foot earthen dike securing a retention pond at the Tennessee Valley Authority's (TVA) Kingston Fossil Plant holding five decades of coal fly ash gave way. Most of an estimated 4.1 million cubic meters of saturated coal fly ash fluidized and flowed catastrophically from the pond covering a total land and aquatic area of 300 acres with deposits up to 10 meters deep. This ash spill is the largest volume industrial spill in US history. The sheer size of the spill, and the fact that it has impacted both lentic and lotic systems makes the situation unique. Approximately 90% of the ash flow entered the Emory River proper where the force of the flow pushed ash up to 6 miles upstream and stranded and buried fish and mussels. From the point of the spill the Emory River flows into the Clinch River two river miles downstream which then flows into the impounded Tennessee River at Watts Bar Lake four river miles further downstream. We have estimated that the initial ash flow into the Emory River contained ~3830 tons of the 10 most toxic elements present in fly ash. Preliminary analyses of ash, water, sediments, and fish tissues collected from 6 sites at 5 and 18 days following the dike failure have shown the following: 1) dissolved and/or total available toxic metals (As, Cd, Cr, Cu, Ni, Pb, Se, Tl) in water immediately below the spill exceed protective aquatic life criteria levels; 2) ash and ash-laden sediments from the river have high arsenic levels; 3) fish exposed to ash show several histological alterations indicative of stress from toxic element exposure; 4) fish body burdens of selenium are at and beyond the thresholds of toxicity for reproduction and growth; and 5) chemical analysis of the surface of coal ash cenospheres from surface water samples by Energy Dispersive X-ray analysis (EDS) revealed detectable levels of arsenic (~10,000 ppm) associated with iron oxide gels. The initial collection data suggest the selenium in the fish tissues is legacy selenium from decades of unregulated release of this metal from ash settling ponds at the TVA Kingston plant (EPA Toxic Inventory indicates 3.03lb/day and the TVA dredging plan mentioned 2.8lb/day release to the Clinch River). Selenium body burdens in fish may increase drastically as the selenium released into the aquatic system from the initial spill and subsequent dredging is absorbed and bioaccumulated in the food web. Quarterly sediment and fish sampling will continue to determine the changes in levels of selenium over time.

Project Results

- Estimates of >3830 tons of the 10 most toxic metals present in fly ash were deposited in the Emory River after the dike failure.
- Dissolved and/or total available toxic metals (As, Cd, Cr, Cu, Ni, Pb, Se, Tl) in river water exceeded protective aquatic life criteria levels only within the first weeks following the spill.
- Ash from the spill is transporting metals downstream to the Clinch and Tennessee rivers.
- Fish body burdens of selenium are at and beyond the thresholds of toxicity for reproduction and growth in some species.
- The preliminary data suggest the selenium in the fish tissues is legacy selenium, possibly from decades of unregulated release of this metal from ash settling ponds at the TVA Kingston plant (NPDES permit allows 2.8lb/day release from ponds & EPA Toxic Inventory reports >3lb/day). Further bioaccumulation of selenium and other toxic elements is expected.

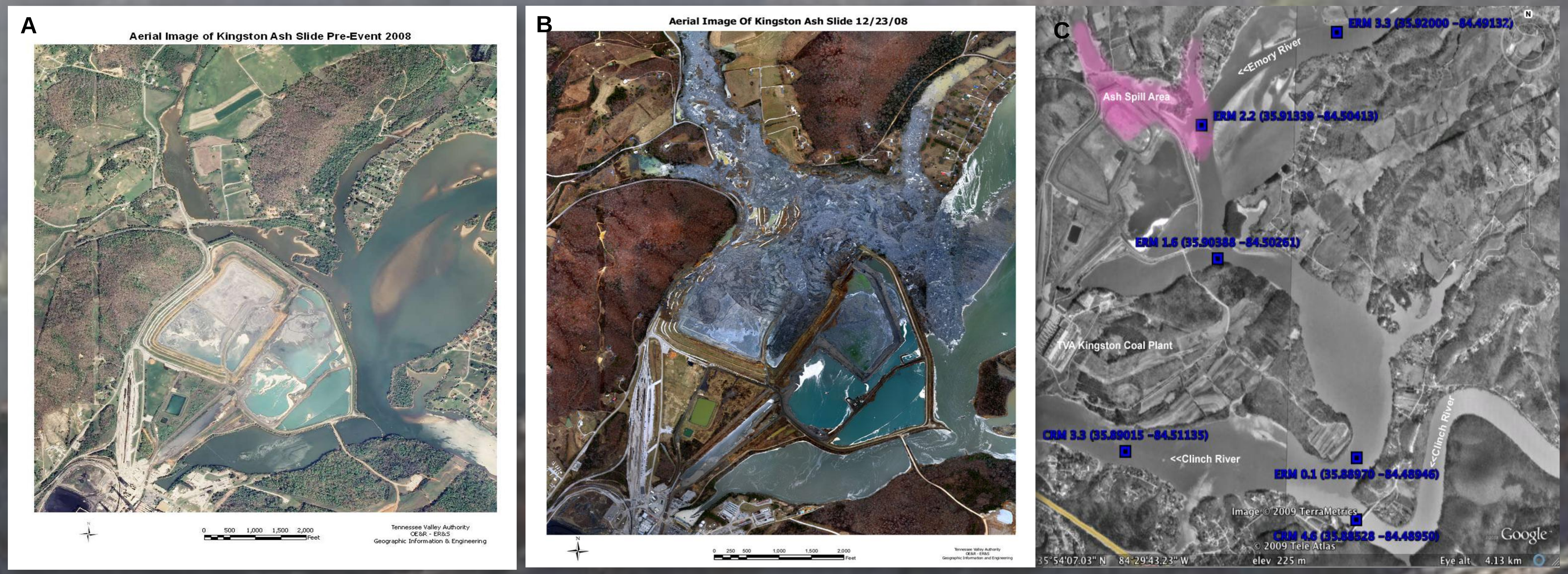


Figure 2. A) Aerial image of the Kingston ash holding ponds before the spill, B) Aerial image of Kingston ash slide post-event, and C) Satellite image of coal fly ash spill area with sampling locations indicated by blue markers. River mile location and latitude and longitude data are included. Approximately 4.1 million cubic meters of ash were released into the Emory River, filling in a 30 ft deep channel and flowed upstream 6 miles..

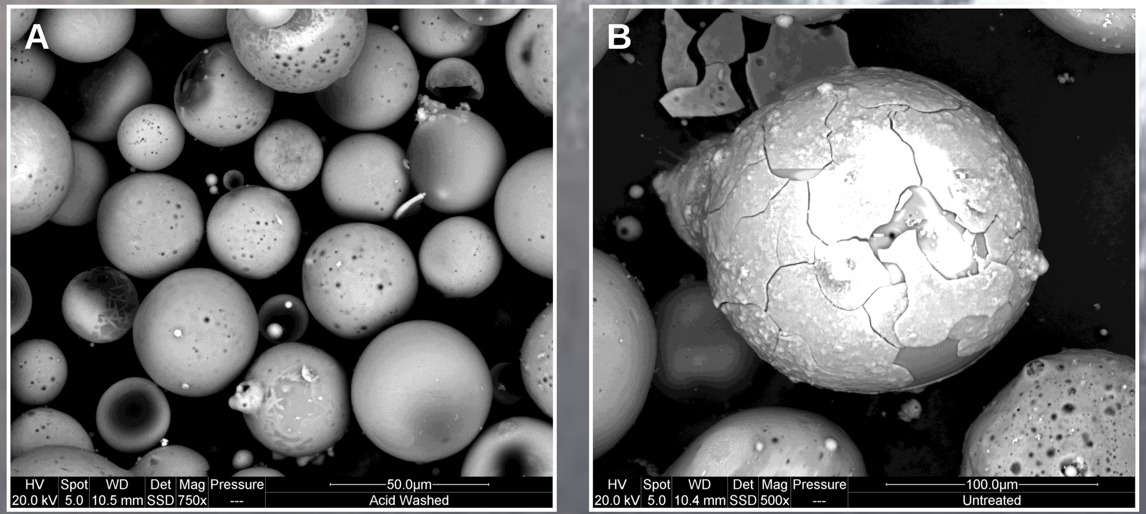


Figure 5. Scanning electron microscopy of A) acid washed cenospheres from surface water samples collected 12-27-08, five days following the spill, and B) untreated cenospheres collected from surface water on 1-9-09.

Conclusions from Scanning Electron Microscopy

The raw ash sample from surface water (i.e. floating cenospheres) contained a heterogeneous mixture of coal ash particles. Notably, ~10% of the ash particles were coated with a secondary mineral gel (see Fig. 6) which consists primarily of iron oxides. Elements of concern (arsenic ~1-2% by weight) are bound to the iron oxides but the validated concentrations of these elements are difficult to determine at this time. As seen above this gel coating was fractured by the drying process and in some cases pieces had sloughed off the ash particle. Analysis of the coating was determined by Energy Dispersive X-ray analysis (EDX).

Further analysis of cenospheres and the gel coating is continuing in the ASU Geology Dept. at the ASU Dewel microscopy facility. It is likely that arsenic is not the only heavy metal that coats the ash particle (Cu, Se, Mn, Pb, etc) have been found in water samples as well). Depending on the outcome of further study, it may be determined that in contrast to "young" particles, recently created by the coal combustion process, "old" particles that come from aged wet ash basins are transformed and coated by years worth of degradation and breakdown processes. The significance of this is that upon release from the ponds, transport of heavy metals into the aquatic environment is possible. However, it is clear from this initial analysis that further study of aged coal ash particles stored in a wet environment is needed before any solid conclusions can be drawn.

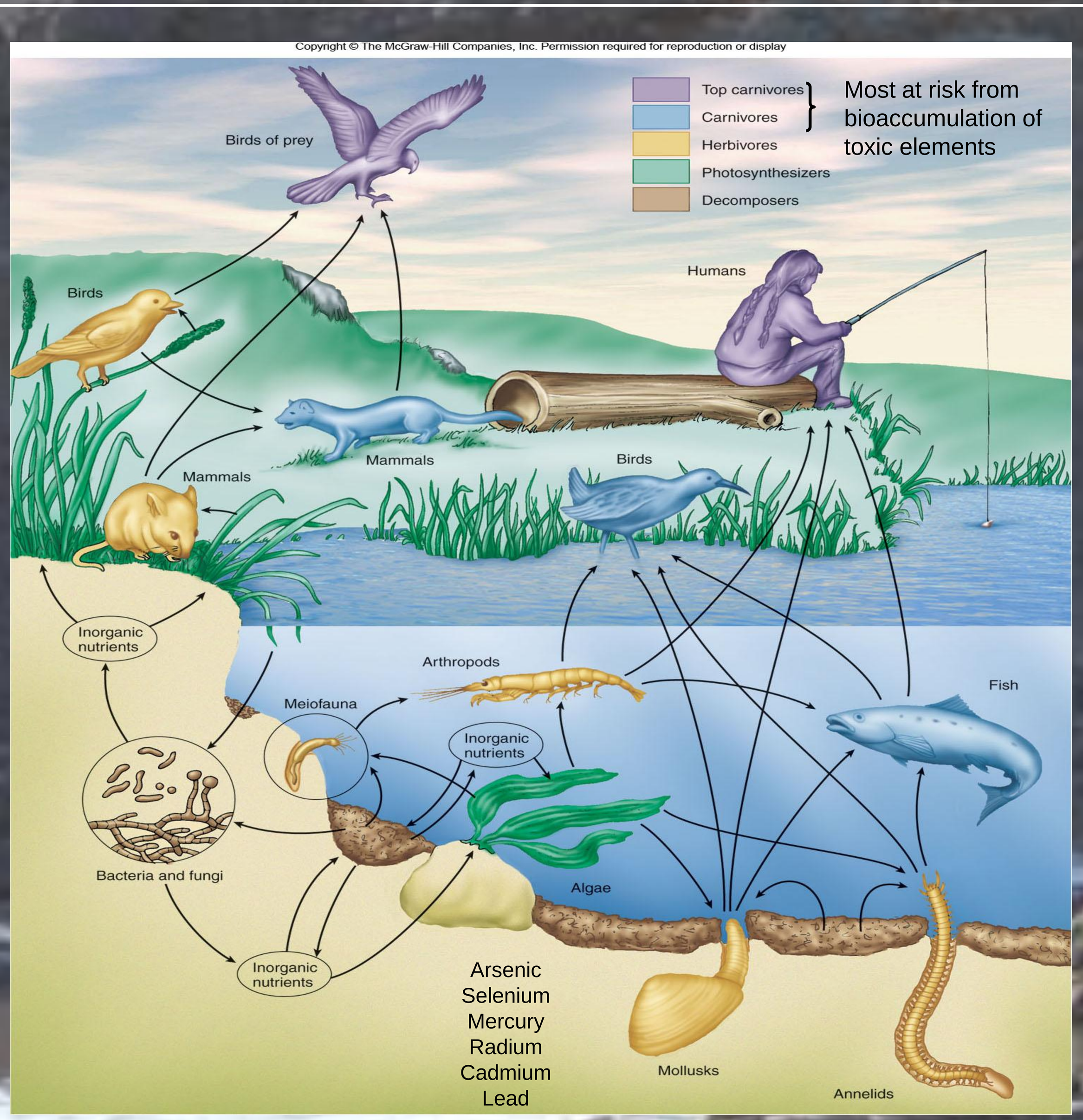


Figure 1. A diagram of the aquatic food web of the Emory, Clinch, and Tennessee River Systems. Toxic elements from the coal fly ash are taken up by all members of the web and some may be biomagnified in animals at the top of the food chain (fish, mammals, and birds)

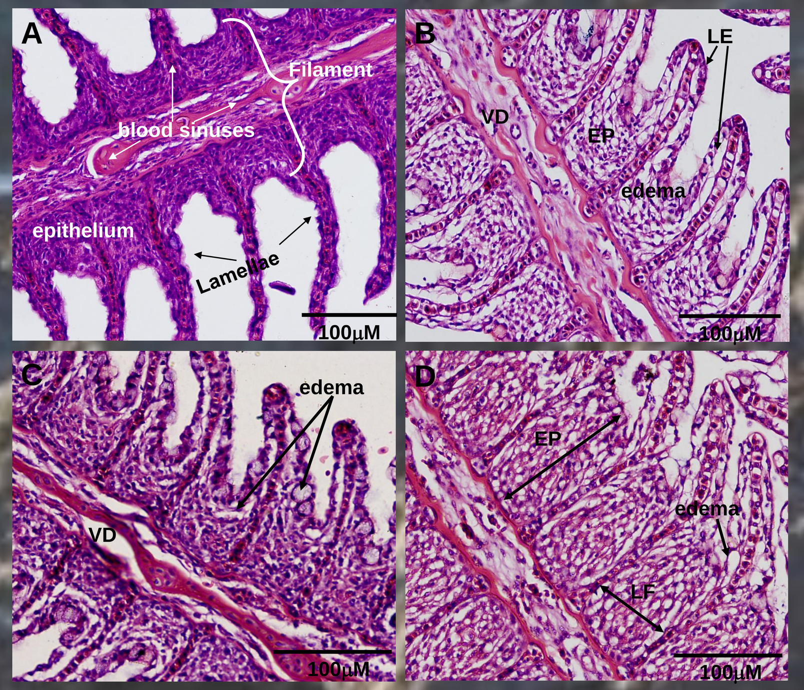
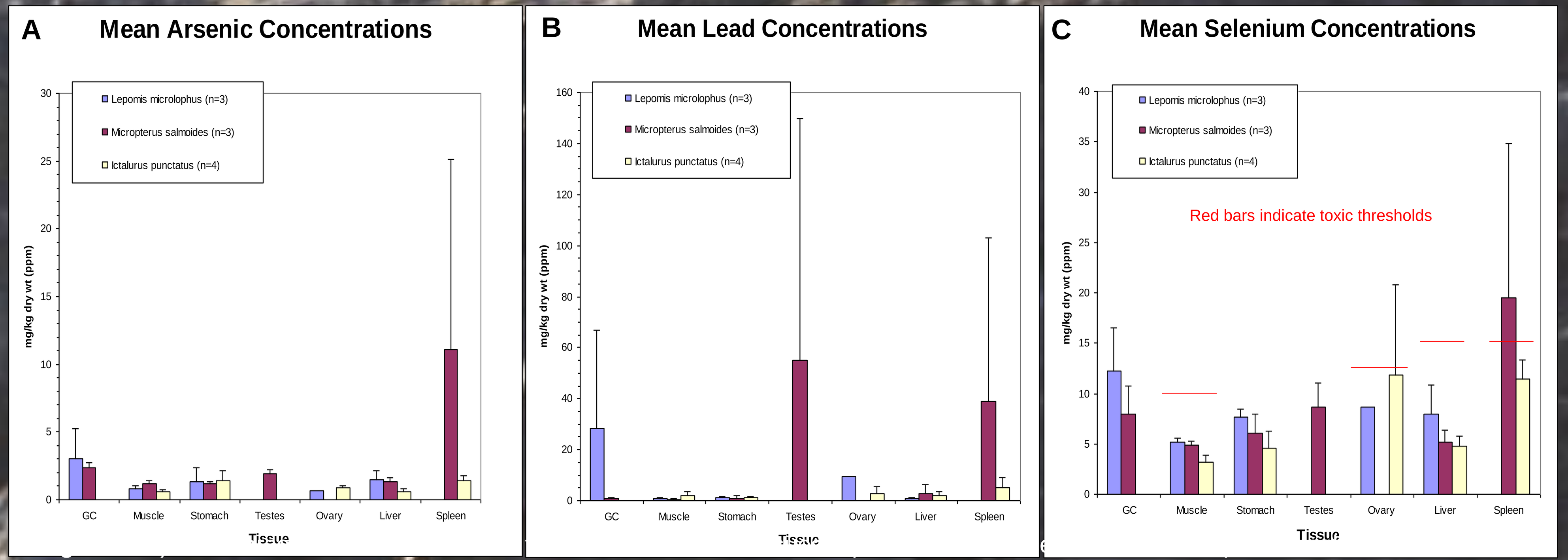


Figure 3. Histological sections of catfish gills (10x) from (A) reference site at TRM 568; (B-D) the ash spill site at ERM 2.2. The reference fish gill (A) shows normal tissue arrangement, while the gills from the 3 ash exposed catfish (B-D) all express pathology consistent with toxic element exposure including edema, vasodilation (VD), epithelial proliferation (EP), lamellar epithelium lifting (LEL), and lamellar fusion (LF).



concentrations. The levels of selenium in the fish are nearing a point at which reproductive failure begins. These reproductive impacts can begin at the toxic thresholds for selenium which are known to occur at approximately 8 ppm in muscle, 10 ppm in ovaries, 12 ppm in the liver and spleen, and 4ppm in whole body (dry weight). There is 100 % reproductive loss when ovaries contain 50-70 ppm selenium. Selenium levels at 2.5 ppb in water can be converted to 25 ppm selenium in fish through biomagnification.

Table 1. Summary of results of sediment analyses for arsenic and selenium content (mean of 3 replicates) for the Jan '09 and Mar '09 samples. In general, the levels at the spill site and just downstream are decreasing (likely due to floodwater translocation of ash, mixing with sediments, and leaching), while levels in the Tennessee River seem to be increasing in arsenic.

Collection Date	Element	Collection Site						
		ERM 14	ERM 3.3	ERM 2.2	ERM 1.5	ERM 0.5	CRM 3.3	TRM 567
Jan 8/9	Arsenic (mg/kg d.w)	n/a	4.073	111.897	65.985	27.360	42.254	12.437
	Selenium (mg/kg d.w)	n/a	0.513	3.859	6.385	3.816	2.820	1.828
March 20/21	Arsenic (mg/kg d.w)	0.712	3.12	82.675	47.263	n/a	18.320	20.299
	Selenium (mg/kg d.w)	0.475	0.221	6.236	3.875	n/a	0.560	1.230

Table 2. Summary of total available elements analysis of Jan 8-9,2009 **surface water** samples, reported in ppm (mg/L). Sample concentrations below detection limits are indicated by BDL. Subsequent sampling in March, April, and July (while dredging has occurred) have shown no exceedances of aquatic life criteria.

Elements	ERM 3.3	ERM 2.2	ERM 1.6	ERM 0.1	CRM 4.6	CRM 3.3	TRM 567	WQ Standard	Comments
Arsenic	BDL	2.667	0.009	BDL	BDL	BDL	BDL	0.010	260x DW standard at spill site, diminishes downstream
Barium	0.030	7.313	0.120	0.079	0.075	0.066	0.083	2.0	3.65x DW standard at spill site, diminishes downstream in Emory River
Cadmium	0.001	0.0150	0.001	0.001	0.001	0.001	0.001	0.015	3x for DW standard at spill site, diminishes downstream
Lead	BDL	0.2434	0.006	0.003	BDL	0.005	BDL	0.015	16x DW standard at spill site, diminishes downstream
Selenium	BDL	0.038	0.004	BDL	0.009	0.007	BDL	0.020, 0.005	1.9x TN acute aquatic life criteria, 7.6 x TN chronic aquatic life criteria

Table 3. Composite of TDEC, ASU, and Clemson fish results for muscle/ovary samples (mg/kg d.w.).

Catfish Collection Sites	TDEC (ICP-MS) Jan	TDEC (ICP-MS) April	ASU (ICP-AES) Jan	ASU (ICP-AES) March	Clemson (ICP-MS) Jan	Clemson (ICP-MS) March
ERM 8	0.79 (n=3)	0.93 (n=3)	-	-	-	-
ERM 3.3	-	-	3.19/11.8 (n=3)	-	-	-
ERM 2	-	-	3.44/11.84(n=3)	-	2.88/11.53 (n=3)	-
ERM 0.5	0.9 (n=4)	-	-	-	-	-
CRM 9.5	0.76 (n=4)	-	-	-	-	-
CRM 1.2	1.72 (n=5)	-	-	-	-	-
TRM 567	-	-	-	2.67/10.72 (n=1)	-	1.25/24.15 (n=1)
Bass						
ERM 14	-	-	-	3.84/5.19 (n=4)	-	-
ERM 8	-	-	-	-	-	-
ERM 3	4.51 (composite)	-	4.9/- (n=3)	-	-	-
ERM 2	-	-	-	3.84/5.13 (n=1)	-	6.98/8.21 (n=1)
ERM 0.5	2.62 (n=8)	-	-	-	-	-
CRM 9.5	2.2 (n=5)	-	-	-	-	-
CRM 5.5	-	-	-	3.76/4.92 (n=3)	-	-
CRM 3.3	-	-	-	4.26/4.7 (n=1)	-	-
CRM 1.2	1.96 (n=4)	-	-	-	-	-
TRM 567	-	-	-	3.36/5.71 (n=4)	-	-
TRM 568	-	-	-	4.73/5.50 (n=2)	-	-